

1 CLAIMS

2 What is claimed is:

3 1. A resonant optical modulator, comprising:

- 4 a) a transmission optical waveguide adapted for transmitting therethrough an optical
5 signal, the transmission optical waveguide having a transverse coupling segment;
6 b) a resonant optical component including at least one circumferential-mode optical
7 resonator, the circumferential-mode optical resonator being positioned so as to be
8 transverse-coupled to the transmission optical waveguide at the transverse-coupling
9 segment thereof, the resonant optical component being substantially resonant with the
10 optical signal;
11 c) a modulator optical component, the modulator optical component being positioned so as
12 to be transverse-coupled to the circumferential-mode optical resonator; and
13 d) a modulator control component, the modulator control component being operatively
14 coupled to the modulator optical component, the modulator optical component and the
15 modulator control component being adapted for modulating, in response to an applied
16 control signal, at least one of i) a level of optical signal power transfer by transverse-
17 coupling between the circumferential-mode optical resonator and the modulator optical
18 component, ii) a level of optical loss of the modulator optical component, and iii) a
19 resonant frequency of the modulator optical component,
20 the modulator control component thereby enabling controlled modulation of a coupling
21 condition between the transmission optical waveguide and the resonant optical
22 component, in turn enabling controlled modulation of a level of transmission of the
23 optical signal through the transmission optical waveguide between a higher operational
24 optical transmission level and a lower operational optical transmission level.

25 2. The resonant optical modulator of Claim 1, the modulator optical component comprising a
26 modulator optical waveguide.

27 3. The resonant optical modulator of Claim 2, the modulator optical waveguide being
28 positioned tangentially with respect to the circumferential-mode optical resonator for
29 transverse-coupling thereto.

30 4. The resonant optical modulator of Claim 3, the modulator optical waveguide comprising a
31 slab waveguide.

- 1 5. The resonant optical modulator of Claim 3, the modulator optical waveguide comprising a
2 laterally-confined optical waveguide.
- 3 6. The resonant optical modulator of Claim 3, the modulator optical waveguide comprising a
4 protruding ridge optical waveguide.
- 5 7. The resonant optical modulator of Claim 2, the modulator optical waveguide being
6 positioned axially relative to the circumferential-mode optical resonator for transverse-
7 coupling thereto.
- 8 8. The resonant optical modulator of Claim 7, the circumferential-mode optical resonator
9 comprising a fiber-ring optical resonator.
- 10 9. The resonant optical modulator of Claim 7, further including a spacer positioned between
11 the circumferential-mode optical resonator and the modulator optical waveguide.
- 12 10. The resonant optical modulator of Claim 1, the modulator optical component comprising a
13 modulator optical resonator.
- 14 11. The resonant optical modulator of Claim 10, the modulator optical resonator being
15 positioned tangentially with respect to the circumferential-mode optical resonator for
16 transverse-coupling thereto.
- 17 12. The resonant optical modulator of Claim 10, the modulator optical resonator being
18 positioned axially relative to the circumferential-mode optical resonator for transverse-
19 coupling thereto.
- 20 13. The resonant optical modulator of Claim 12, the circumferential-mode optical resonator
21 comprising a fiber-ring optical resonator.
- 22 14. The resonant optical modulator of Claim 12, further including a spacer positioned between
23 the circumferential-mode optical resonator and the modulator optical resonator.
- 24 15. The resonant optical modulator of Claim 10, the modulator optical resonator comprising a
25 second circumferential-mode optical resonator.
- 26 16. The resonant optical modulator of Claim 10, the modulator optical resonator comprising a
27 ring optical waveguide.
- 28 17. The resonant optical modulator of Claim 10, the circumferential-mode optical resonator and
29 the modulator optical resonator being substantially co-planar.
- 30 18. The resonant optical modulator of Claim 10, the circumferential-mode optical resonator and
31 the modulator optical resonator being substantially orthogonal.

- 1 19. The resonant optical modulator of Claim 10, the circumferential-mode optical resonator and
2 the modulator optical resonator being substantially parallel.
- 3 20. The resonant optical modulator of Claim 1, the modulator optical component and the
4 modulator control component being adapted for modulating, in response to the control
5 signal, the level of optical loss of the modulator optical component.
- 6 21. The resonant optical modulator of Claim 20, the modulator optical component including an
7 electro-absorptive material, the modulator control component including control electrodes
8 adapted for applying an electronic control signal to the electro-absorptive material for
9 modulating the level of optical loss of the modulator optical component.
- 10 22. The resonant optical modulator of Claim 21, the electro-absorptive material including a
11 semi-conductor-based material.
- 12 23. The resonant optical modulator of Claim 21, the electro-absorptive material including a
13 quantum well material.
- 14 24. The resonant optical modulator of Claim 21, the electro-absorptive material including an
15 InGaAsP multi-quantum-well material.
- 16 25. The resonant optical modulator of Claim 21, the electro-absorptive material including a
17 multi-layer reflector structure.
- 18 26. The resonant optical modulator of Claim 20, the modulator optical component including a
19 non-linear optical material, the modulator control component including at least one optical
20 component for transmitting an optical control signal to the non-linear optical material for
21 modulating the level of optical loss of the modulator optical component.
- 22 27. The resonant optical modulator of Claim 1, the modulator optical component and the
23 modulator control component being adapted for modulating, in response to the control
24 signal, the level of optical signal power transfer by transverse-coupling between the
25 circumferential-mode optical resonator and the modulator optical component.
- 26 28. The resonant optical modulator of Claim 27, the modulator optical component including an
27 electro-optic material, the modulator control component including control electrodes
28 adapted for applying an electronic control signal to the electro-optic material for modulating
29 the level of optical signal power transfer by transverse-coupling between the
30 circumferential-mode optical resonator and the modulator optical component.

- 1 29. The resonant optical modulator of Claim 28, the electro-optic material including a semi-
2 conductor-based material.
- 3 30. The resonant optical modulator of Claim 28, the electro-optic material including a quantum
4 well material.
- 5 31. The resonant optical modulator of Claim 28, the electro-optic material including an
6 InGaAsP multi-quantum-well material.
- 7 32. The resonant optical modulator of Claim 28, the electro-optic material including a multi-
8 layer reflector structure.
- 9 33. The resonant optical modulator of Claim 28, the electro-optic material including a polymeric
10 material.
- 11 34. The resonant optical modulator of Claim 27, the modulator optical component including a
12 non-linear optical material, the modulator control component including at least one optical
13 component for transmitting an optical control signal to the non-linear optical material for
14 modulating the level of optical signal power transfer by transverse-coupling between the
15 circumferential-mode optical resonator and the modulator optical component.
- 16 35. The resonant optical modulator of Claim 1, the modulator optical component comprising a
17 modulator optical resonator, the modulator optical resonator and the modulator control
18 component being adapted for modulating, in response to the control signal, the resonant
19 frequency of the modulator optical resonator.
- 20 36. The resonant optical modulator of Claim 35, the modulator optical resonator including an
21 electro-optic material, the modulator control component including control electrodes
22 adapted for applying an electronic control signal to the electro-optic material for modulating
23 the resonant frequency of the modulator optical resonator.
- 24 37. The resonant optical modulator of Claim 36, the electro-optic material including a semi-
25 conductor-based material.
- 26 38. The resonant optical modulator of Claim 36, the electro-optic material including a quantum
27 well material.
- 28 39. The resonant optical modulator of Claim 36, the electro-optic material including an
29 InGaAsP multi-quantum-well material.
- 30 40. The resonant optical modulator of Claim 36, the electro-optic material including a multi-
31 layer reflector structure.

- 1 41. The resonant optical modulator of Claim 36, the electro-optic material including a polymeric
2 material.
- 3 42. The resonant optical modulator of Claim 35, the modulator optical resonator including a
4 non-linear optical material, the modulator control component including at least one optical
5 component for transmitting an optical control signal to the non-linear optical material for
6 modulating the resonant frequency of the modulator optical resonator.
- 7 43. The resonant optical modulator of Claim 1, the transmission optical waveguide comprising a
8 transmission fiber-optic waveguide.
- 9 44. The resonant optical modulator of Claim 43, the transverse-coupling segment of the
10 transmission optical waveguide including a fiber-optic-taper segment.
- 11 45. The resonant optical modulator of Claim 43, the transverse-coupling segment of the
12 transmission optical waveguide including a side-etched segment.
- 13 46. The resonant optical modulator of Claim 43, the transmission fiber-optic waveguide
14 including single-mode optical fiber.
- 15 47. The resonant optical modulator of Claim 43, the transmission fiber-optic waveguide
16 including polarization-maintaining optical fiber.
- 17 48. The resonant optical modulator of Claim 47, the polarization maintaining optical fiber being
18 elliptical-core optical fiber.
- 19 49. The resonant optical modulator of Claim 47, the polarization-maintaining optical fiber being
20 "panda" optical fiber.
- 21 50. The resonant optical modulator of Claim 1, the circumferential-mode optical resonator
22 comprising at least one fiber-ring resonator, the fiber-ring resonator including a transverse
23 resonator segment integral with a resonator optical fiber between first and second segments
24 of the resonator optical fiber and having a circumferential optical path length sufficiently
25 different from a circumferential optical path length of an immediately adjacent portion of at
26 least one of the first and second segments of the resonator optical fiber so as to enable the
27 resonator segment to support a resonant optical mode near an outer circumferential surface
28 of the fiber-ring optical resonator.
- 29 51. The resonant optical modulator of Claim 50, wherein the resonator segment is greater than
30 about 10 μm in diameter.

- 1 52. The resonant optical modulator of Claim 50, wherein the resonator segment is greater than
2 about 20 μm in diameter.
- 3 53. The resonant optical modulator of Claim 50, wherein the resonator segment is greater than
4 about 100 μm in diameter.
- 5 54. The resonant optical modulator of Claim 50, wherein the resonator segment is less than
6 about 2000 μm in diameter.
- 7 55. The resonant optical modulator of Claim 50, wherein the resonator segment is less than
8 about 200 μm in diameter.
- 9 56. The resonant optical modulator of Claim 50, wherein the resonator segment is less than
10 about 150 μm in diameter.
- 11 57. The resonant optical modulator of Claim 50, wherein a resonator segment is larger in radius
12 than the immediately adjacent portion of at least one of the first and second segments of the
13 resonator optical fiber, and the resonator segment radius exceeds the adjacent portion radius
14 by a resonator segment step size.
- 15 58. The resonant optical modulator of Claim 57, wherein the step size is greater than about 0.1
16 μm .
- 17 59. The resonant optical modulator of Claim 57, wherein the step size is greater than about 0.5
18 μm .
- 19 60. The resonant optical modulator of Claim 57, wherein the step size is less than about 20 μm .
- 20 61. The resonant optical modulator of Claim 57, wherein the step size is less than about 1.5 μm .
- 21 62. The resonant optical modulator of Claim 50, wherein the resonator segment is greater than
22 about 1 μm in width.
- 23 63. The resonant optical modulator of Claim 50, wherein the resonator segment is greater than
24 about 2 μm in width.
- 25 64. The resonant optical modulator of Claim 50, wherein the resonator segment is less than
26 about 10 μm in width.
- 27 65. The resonant optical modulator of Claim 50, wherein the resonator segment is less than
28 about 4 μm in width.
- 29 66. The resonant optical modulator of Claim 50, the resonator optical fiber including at least one
30 delocalized-optical-mode suppressor.

- 1 67. The resonant optical modulator of Claim 50, the transmission optical waveguide comprising
2 a transmission fiber-optic waveguide, the transverse-coupling segment of the transmission
3 optical waveguide including a fiber-optic taper segment, the resonator optical fiber
4 including a fiber-optic-taper positioning-and-support structure for engaging the fiber-optic
5 taper segment so as to transverse-couple the fiber-ring resonator and the fiber-optic taper
6 segment.
- 7 68. The resonant optical modulator of Claim 67, the fiber-optic-taper segment being engaged by
8 the fiber-taper positioning-and-support structure at a location axially displaced from an axial
9 midpoint of the fiber-ring resonator so as to substantially reduce undesirable fiber-optic-
10 taper-induced optical loss of the fiber-ring resonator.
- 11 69. The resonant optical modulator of Claim 67, the fiber-optic-taper segment being engaged by
12 the fiber-taper positioning-and-support structure at a location radially displaced from an
13 outer circumference of the fiber-ring resonator so as to substantially reduce undesirable
14 fiber-optic-taper-induced optical loss of the fiber-ring resonator.
- 15 70. The resonant optical modulator of Claim 50, the transmission optical waveguide comprising
16 a transmission fiber-optic waveguide, the transverse-coupling segment of the transmission
17 optical waveguide including a fiber-optic taper segment of the transmission fiber-optic
18 waveguide, the fiber-optic-taper segment being partially wrapped around the fiber-ring
19 resonator near a portion of an outer circumference thereof.
- 20 71. The resonant optical modulator of Claim 70, wherein the spatial extent of the wrapped
21 portion of the outer circumference of the wrapped fiber-ring resonator subtends an angle less
22 than about 180°.
- 23 72. The resonant optical modulator of Claim 70, wherein the spatial extent of the wrapped
24 portion of the outer circumference of the wrapped fiber-ring resonator subtends an angle
25 greater than about 45°.
- 26 73. The resonant optical modulator of Claim 70, wherein the spatial extent of the wrapped
27 portion of the outer circumference of the wrapped fiber-ring resonator is greater than about
28 10 μm .
- 29 74. The resonant optical modulator of Claim 70, wherein the spatial extent of the wrapped
30 portion of the outer circumference of the wrapped fiber-ring resonator is greater than about
31 50 μm .

- 1 75. The resonant optical modulator of Claim 70, wherein the spatial extent of the wrapped
2 portion of the outer circumference of the wrapped fiber-ring resonator is less than about 500
3 μm .
- 4 76. The resonant optical modulator of Claim 70, wherein the spatial extent of the wrapped
5 portion of the outer circumference of the wrapped fiber-ring resonator is less than about 200
6 μm .
- 7 77. The resonant optical modulator of Claim 70, wherein the spatial extent of the wrapped
8 portion of the outer circumference of the wrapped fiber-ring resonator yields about 90%
9 transmission of a substantially resonant optical signal through the transmission fiber-optic
10 waveguide in the absence of another optical element transverse-coupled to the fiber-ring
11 resonator.
- 12 78. The resonant optical modulator of Claim 1, an over-coupled condition between the
13 transmission optical waveguide and the circumferential-mode optical resonator
14 corresponding to the higher operational optical transmission level, a substantially critically-
15 coupled condition between the transmission optical waveguide and the circumferential-
16 mode optical resonator corresponding to the lower operational optical transmission level.
- 17 79. The resonant optical modulator of Claim 1, a substantially critically-coupled condition
18 between the transmission optical waveguide and the circumferential-mode optical resonator
19 corresponding to the lower operational optical transmission level, an under-coupled
20 condition between the transmission optical waveguide and the circumferential-mode optical
21 resonator corresponding to the higher operational optical transmission level.
- 22 80. A method for controlling transmission of an optical signal through a transmission optical
23 waveguide, the method comprising the step of applying a control signal to a modulator
24 control component, the modulator control component being operatively coupled to a
25 modulator optical component, the modulator optical component being positioned so as to be
26 transverse-coupled to a resonant optical component, the resonant optical component
27 including at least one circumferential-mode optical resonator, the resonant optical
28 component being substantially resonant with the optical signal, the resonant optical
29 component being transverse-coupled to the transmission optical waveguide, the modulator
30 optical component and the modulator control component being adapted for modulating, in
31 response to the applied control signal, at least one of i) a level of optical signal power

1 transfer by transverse-coupling between the circumferential-mode optical resonator and the
2 modulator optical component, ii) a level of optical loss of the modulator optical component,
3 and iii) a resonant frequency of the modulator optical component, the modulator control
4 component, thereby enabling controlled modulation of a coupling condition between the
5 transmission optical waveguide and the circumferential optical resonator, in turn enabling
6 controlled modulation of a level of transmission of the optical signal through the
7 transmission optical waveguide between a higher operational optical transmission level and
8 a lower operational optical transmission level.

9 81. The method of Claim 80, the circumferential-mode optical resonator comprising a fiber-ring
10 optical resonator.

11 82. The method of Claim 80, the transmission optical waveguide comprising an optical fiber
12 having a fiber-optic taper segment adapted for transverse-coupling.

13 83. The method of Claim 80, the circumferential-mode optical resonator comprising a fiber-ring
14 optical resonator, the transmission optical waveguide comprising an optical fiber having a
15 fiber-optic taper segment adapted for transverse-coupling, the transmission optical
16 waveguide being positioned so as to be transverse-coupled to the fiber-ring optical resonator
17 at the fiber-optic taper segment.
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